ture's energies; and the inventions of a new century shall justify every one of Charles Sumner's 'prophetic voices,' from those of Seneca to those of Cobden, De Tocqueville and that orator, seer and prophet, Sumner himself. Seneca's continent has appeared and there are no more geographical worlds to conquer; but there are greater worlds still accessible to the scientific explorer. The prophecy of the 'bought servant,' George Webb, became true with the birth of a new nation:

> Rome shall lament her ancient fame declined
> And Philadelphia be the Athens of mankind.

Meantime, the nation, as prophesied by Sheridan, shall thus maintain a 'name and government rising above the nations of Europe with a simple but commanding dignity that wins at once the respect, the confidence and the affection of the world.'

And, in all this, the man of science, seer, revealer and prophet, shall play the noblest part.

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*ATTENUATION AND DISTORTION ON LONG-DISTANCE TELEPHONE AND POWER TRANSMISSION LINES REGARDED AS HYDRODYNAMIC PHENOMENA.**

THE analogy between a steady flow of water in a long pipe under the action of the constant head and a continuous current of electricity under some constant pressure such as is furnished by one or more cells of a battery, has often been employed to give a clear elementary physical conception of the mathematical relations expressed by Ohm's law. In this case the applied pressure is gradually consumed by the resistance experienced by the current, and in strict analogy with the flow of water, the loss per unit of length is proportional to the product of the square of the current and the first power of the resistance. So far as the mathematical relations are concerned the two problems are identical.

It is the object of this paper to extend this hydrodynamic analogy to the more complicated case of long-distance transmission by alternating currents in general.

Telephone transmission has been specifically mentioned in the title in order to include the general case of variable frequency. The importance of thus extending and enlarging this analogy will be evident when we reflect that all the complicated phenomena of long-distance electrical power transmission, by any combination of land lines and cables with their sending and receiving apparatus, may be completely reproduced in all its details of operation by simple pumping machinery with its transmission pipes and air chambers, whose manner of operation may be made clear to any one without the aid of higher analysis. Let us first take the case of a double-acting pump cylinder and piston in which the two ends of the cylinder are connected by a simple pipe or by-pass without valves. When this apparatus is filled with water and the piston is moved back and forth by a uniformly rotating crank, the water is forced through the by-pass alternately from one end of the cylinder to the other. If the by-pass is short, the resistance to motion may be taken as due to fluid friction only, since the inertia of the water may then be disregarded. This is in every particular analogous in the manner of its operation to a sinusoidal electromotive force acting in a circuit whose induction and capacity may be disregarded in comparison with its ohmic resistance.

But in case the pipe connecting the ends of the pump cylinder be made very long and the size sufficient to greatly reduce the friction, we may disregard this in com-

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parison with the resistance due to the inertia of the water. The resistance due to inertia is proportional to the product of the mass of the water moved by its acceleration. Since this acceleration is greatest at the beginning of the stroke and vanishes at the middle of the stroke, where it changes to a retardation of amount increasing to the end of the stroke, it is evident that the phase of the current lags a quarter of a revolution or period behind that of the pressure, the pressure being a maximum at the beginning of the stroke, and the current a maximum at the middle of the stroke. During the retardation of the piston the inertia of the water acts to drive the piston forward, and (disregarding friction) as much energy is returned to the piston during retardation as is exerted by it during acceleration, so that on the whole no loss of energy occurs during the stroke. In these particulars this case differs from that previously considered, where the pressure is in phase with the current and energy is expended against resistance during the entire stroke.

Now suppose that fluid friction and inertia coexist in the connecting pipe; it is evident that their coexistence does not affect the separate actions which have been described. The current or flow back and forth is that due to the reciprocating motion of the piston, and the pressure is the resultant of the two pressures already described, differing in phase by a quarter of a period. The lag of the current will, therefore, be less than a quarter of a period.

The inertia of the water is entirely analogous to the self-induction of an electric circuit and the case of combined fluid friction and inertia is mathematically in every particular the same as an alternating current circuit having distributed ohmic resistance and self induction.

Next let us imagine the short by-pass first considered to be sufficiently increased in diameter to make it a globular chamber as large or larger than the cylinder itself, and let it be furnished with an elastic diametral diaphragm (of sheet rubber, for example) which occupies a diametral position whenever the piston is at the middle of the stroke. It is evident that when the piston is at the beginning of the stroke the tension of the stretched diaphragm exerts a negative pressure or suction to force the piston forward in its stroke, which vanishes at the middle of the stroke, after which the pressure exerts a retardation whose amount increases to a maximum at the end of the stroke. But the total energy exerted by the diaphragm and restored to it is equal.

The action of the diaphragm differs from the action of the inertia of the water previously considered in the one particular only: it exerts its greatest forward pressure at the instant the inertia exerts its greatest back pressure, consequently when we disregard fluid friction, the phase of the current is one quarter of a period in advance of the pressure.

It thus appears that the effect of such a diaphragm is opposite to that of the inertia of the water, so that a diaphragm having sufficient tension would completely destroy the effect of the inertia of the water. The general effect of this arrangement is to relieve to a greater or less extent the greater pressures, positive or negative, at each end of the stroke arising from the inertia of the water. Furthermore it may be noticed that a somewhat different device from that just mentioned might be employed, whose resultant action would nevertheless be of the same nature. For example, instead of enlarging the by-pass let two equal air chambers be placed on it, one at each end of the cylinder. This is, in fact, the manner in which relief is actually obtained in pumping machinery, from the shock and greatly increased pressure at the beginning

and end of the stroke arising from the inertia of the water. Mathematically the effect is the same as that of the diaphragm previously described.

The operation of the diaphragm and air chambers just considered is strictly analogous to that of capacity in an alternating-current circuit, the diaphragm to capacity in series, and the two air chambers to capacity in shunt, and by these self induction may be neutralized to a greater or less extent, according to their relative amounts.

We have thus far considered merely the peculiarities of the transmitting or connecting pipes in their relation to the double-acting force pump regarded as the source of energy. We need next to consider a receiving pump which shall take and utilize the energy not expended in fluid friction. Let the receiving pump be assumed at first to be exactly like the force pump, and to actuate a crank, fly wheel and other machinery on which energy is expended uniformly. The crank end of this second cylinder is connected directly by a pipe with the crank end of the force pump, and the other ends likewise. In this case the energy expended in fluid friction and inertia may be neglected in comparison with the energy transmitted; this arrangement will transmit power from the driving crank to the driven crank much as would a belt or train of cog wheels. But suppose now that the second cylinder is connected to the first by very long pipes, miles long, for example, in which the inertia of the water becomes a controlling factor of the transmission. It would evidently become practically impossible to make the water oscillate with any rapidity in such a closed pipe under ordinary circumstances. But let there be a series of air chambers uniformly distributed along the entire length of the connecting pipes, or, what would amount to nearly the same thing, let the pipe be an elastic hose requiring pressure to enlarge or diminish its cross section.

This will at once entirely change the circumstances of the case, for the air chambers near the force pump will readily receive the water as it flows from the force pump and transmit it to those next along the line and so on, so that a wave of pressure will pass along the pipe and at the same velocity a wave of current will pass having its maximum flow at points where certain high pressure air chambers are discharging into those next along the line. By these progressive pressure and current waves, energy will be transmitted to the working cylinder which need not in this case be of the same cubic capacity as the force pump. Several complete waves may be in progress of transmission along the pipe at once. The frequency of oscillation in the working cylinder will be equal to that of the force pump, a number which may be computed in any given case. But the waves will lag in phase behind those of the force pump to an amount due to the number of waves and fractions thereof in progress of transmission along the line, and to the inertia of the working piston, etc.

It is evident that when the two cylinders are equal in every respect, except that the piston of the second cylinder is of such large mass that its inertia is great and when in addition we may disregard fluid friction, and the fly wheel of the second cylinder is running idle, that no work is expended in the system. In this case the second piston will originate transmission waves precisely as does the first but in opposite direction. The resultant of these equal and opposite progressive waves will be a system of stationary waves along the line. Whenever the amount of energy used at the working cylinder is small compared with the total energy, kinetic and potential, at and near the receiving apparatus the waves originating there will approach

the magnitude of those received by it. Any discontinuity of mass in the current flowing in the pipe, as for example, mercury in place of water for some part of the length of the pipe, will originate reflected or return waves. To insure good transmission, little or no discontinuity in the distribution of the inertia along the pipe should occur at any point such as would be due to changes of size or otherwise.

All these results are equally true of alternating-current circuits.

It may be shown from elementary considerations that the progressive velocity of the waves in the transmission pipe under consideration is constant for all frequencies of oscillation in case of a pipe in which the friction may be disregarded, but that the velocity increases as the square root of the frequency in any case where the inertia of the current may be disregarded. The case of the unequal velocity of the waves propagating the harmonic components of sounds in telephonic transmission by reason of their difference of pitch, which is one cause of the distortion of sound in long-distance telephone transmission, has been treated at length in the researches of Dr. Pupin who has investigated very fully the inductive (or inertia) loading necessary to render lines practically distortionless. This is equally a hydrodynamic phenomenon.

The one question remaining for elucidation is that of the attenuation or gradual diminution of amplitude of waves as they progress along the line.

It may be readily shown that in both of the two extreme cases already considered, viz., those in which either friction or inertia is disregarded, that the logarithm of the reciprocal of the amplitude, or intensity of the wave at any point, varies directly as the product of the distance of the point from the source of the wave by its velocity. Since this velocity has already been shown to be constant in case the fluid friction may be disregarded and to increase with the frequency in case the inertia is disregarded, it is evident that attenuation depends upon frequency in case of fluid friction without inertia, but it is independent of frequency in case of inertia without fluid friction. Such unequal attenuation in the telephone obliterates to a greater or less extent tones of high pitch before it does those of lower pitch. It is therefore necessary to distinct transmission that the self induction of the line should be large enough to store a large amount of kinetic and potential energy in the wave motion along the line, which in all its aspects is strictly analogous to the wave motion propagated in the water in the apparatus just described.

THE CARNEGIE INSTITUTION.

THE officers of the Carnegie Institution have appointed advisory committees and have invited suggestions from men of science. The executive committee has therefore under consideration a large number of reports and recommendations, but as these must in large measure be regarded as confidential, it is probable that the committee would welcome a public discussion of the entire question of the endowment of scientific research. SCIENCE appears to be the best place for such discussion; and it would doubtless be for the common good if those who are interested in the subject would make known their views before the meeting of the trustees in November. At that time a definite policy may be adopted, which cannot thereafter be altered. There are so many diverse possibilities and conflicting interests that these can only be sifted and reconciled by full and free discussion.

It appears that the Carnegie Institution can either undertake certain large plans for the promotion of science or can assist a great number of special researches,